REMARKS

Claims 1-21 are currently pending in this application, with Claims 1-8 and 14-16 having been withdrawn from consideration.

In the Office Action, the Examiner has again rejected Claims 9-13 and 17-21 under 35 U.S.C. §112, first paragraph, as not being enabling, Claims 9-13 and 17-21 under 35 U.S.C. §112, second paragraph, as being incomplete, and as being indefinite, Claims 9-12 and 17-20 under 35 U.S.C. §102(e) as being anticipated by *Tong et al.* (U.S. 6,744,744 B1), and Claims 13 and 21 under 35 U.S.C. §103(a) as being unpatentable over *Tong* in view of *Azaren et al.* (U.S. 5,357,249). Additionally, the Examiner has again objected to the speciation.

With regard to the Examiner's objection to the specification, the Examiner asserts that definitions of the terms "complementary code", "perfect complementary code", and "quasi-complementary code", which are critical and essential to the practice of the present invention, are not enabled by the disclosure.

These terms are all used in the paragraph starting on page 5, line 16, which reads as follows:

> The present invention provides a QCTC generating method for a system using channel interleaving and a method of generating QCTCs in a predetermined way irrespective of a variable code length in a system requiring QCTCs with a variety of code rates. A QCTC is defined as a complementary code generated using a turbo code. The QCTC is not a perfect complementary code as noted from the term "quasi" because a sub-code includes repeated symbols and has a different characteristic such as error correcting capability from another sub-code.

As previously argued, it is respectfully submitted that a complementary code of a turbo code is known in to one skilled in the art. Additionally, the paragraph above explains that the QCTC is

referred to as such, since it is not a "perfect complementary code", which we believe is also known to one skilled in the art, because a sub-code includes repeated symbols and has a different characteristic from another sub-code. More specifically, we believe that the terms used to describe the QCTC, i.e., "complementary code" and "perfect complementary code", are known to one skilled in the art. Therefore, we believe that the definition of QCTC in the specification is enabling *to one skilled in the art.*

With regard to the Examiner's rejection of Claims 9-13 and 17-21 under 35 U.S.C. §112, first paragraph, as not being enabling, the Examiner takes up the same issue with the terms "complementary code", "perfect complementary code", and "quasi-complementary code". However, as indicated above, these terms are known to one skilled in the art and would therefore be enabling within the disclosure of the application and the pending claims.

In order to further clarify these terms to the Examiner, submitted herewith are "OFDMA PHY Enhancements using Hybrid ARQ" and "Quasi-Complementary Turbo Codes (QCTC) For Applications In High-Data-Rate Systems", which further explain QCTCs and the related art.

Further, the Examiner asserts that Claims 10 and 18 are rejected because the term "partial bit reversal order (PBRO) interleaving" is not enabling. However, this method of interleaving is well known to one skilled in the art. See also U.S. Patent 6,910,110. Accordingly, the Examiner is incorrect with this rejection.

With regard to the rejection of Claims 9-13 and 17-21 under 35 U.S.C. §112, second paragraph, as being incomplete, the Examiner asserts that where Claim 9 recites "a QCTC generator for generating a sub-code of a QCTC", there is an omitted structural cooperative relationship between "a QCTC generator" and "a QCTC", and between "a sub-code of a QCTC" and "a QCTC".

Regarding the rejections under §112, second paragraph, the Examiner maintained that the QCTC is not defined to his liking or understanding anywhere in the specification. The following description of a QCTC is presented to the Examiner for his review.

description of a QCTC is presented to the Examiner for his review.

> A quasi-complementary turbo code (QCTC) is a code produced in an apparatus that includes a turbo encoder for generating information symbols and first and second parity symbols from an information bit stream, and a sub-code generator for generating sub-codes from the information symbols and the first and second parity symbols using puncturing matrices. The sub-code generator selects all of the information symbols, if a difference between the number Ns of selected symbols in the initial puncturing matrix and the number of the columns in the initial puncturing matrix is equal to or greater than a number of component encoders in the turbo encoder, and selects a number of first and second parity symbols equal to the difference. The QCTC is referred to a being "quasi-complementary" because the codes are not strictly complementary since repeated symbols do exist, but each sub-code exhibits a unique characteristic that enables the sub-codes to be distinguished from each other even though they are not complementary.

The Examiner asserts with regard to Claims 12, 20, and 13, i.e., that there is no structural cooperative relationship between the "symbol repeater" and the "QCTC generator", or between "serially concatenated symbol sequences" and the recursively selected "serially concatenated symbol sequence". Applicants respectfully request a clear and concise rejection that can be addressed.

With regard to the rejection of Claims 9-13 and 17-21 under 35 U.S.C. §112, second paragraph, as being indefinite, the Examiner takes issue with the phrase "at a given starting position" in Claims 9 and 17. More specifically, the Examiner asserts that it is not clear how a predetermined number of symbols can be selected from a serially concatenated symbol sequence at a given position, because a starting symbol is only one symbol. Claims 9 and 17 have been amended to further clarify the claims. It is respectfully submitted that this language is clear.

For example, as we previously argued, if there is a symbol sequence of ten symbols, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and a predetermined number of symbols are selected, e.g., four, at a given starting

position of the symbol sequence, e.g., the third position/symbol, then symbols 3, 4, 5, and 6 would be selected.

Based on this example, it is respectfully submitted that Claims 9 and 17 are proper.

Further, the Examiner asserts that it is not clear what "according to the coding rate" refers to in Claims 9 and 17. Again, this simply means the given starting point is determined according to (or based on) the coding rate. The Examiner asserts that determining the given starting point based on the coding rate is indefinite because it is not clear how the coding rate is used to determine the starting point. However, since these claims do not define how the coding rate is used to determine the starting point, it is important to note that they do not have to. That is, these claims merely recite, in a proper manner, that the starting point is determined using the coding rate. The specific manner is which the coding rate is used is narrower in scope than desired for these claims and therefore, is not included. Examples for determining given starting point according to coding rate are illustrated on the lower parts of Figures 1 to 3 and described on corresponding descriptions, and a rule for determining given starting point is described in equation (9) of page 18.

With regard to independent Claims 9 and 17, the Examiner asserts that *Tong* teaches all the recitations of these claims.

To make a proper rejection under 35 U.S.C. 102, "[n]o question of obviousness is present. In other words, for anticipation under 35 U.S.C. 102, the reference must teach every aspect of the claimed invention." (See MPEP 706.02 (IV))

However, Claims 9 and 17 recite an apparatus and method, respectively, for generating a QCTC and sub-codes of a QCTC. There is no disclosure in *Tong* for any of these recitations.

The Examiner asserts that the following components of the present invention correspond to components in Figure 5 Tong et al.

Present Application	Tong et al.
a turbo encoder	Turbo Coder 90
an interleaver	Interleaver 93
a multiplexer	Selector 97
a symbol concatenator	
a QCTC generator	Repetition Generator 96

However, the Examiner's assertions are not proper at least based on the following considerations.

First, the Examiner asserts that components of the present invention are identical to components of Tong et al. and states that when a multiplexer and a symbol concatenator are regarded as a component, this component receives parallel inputs from three channels and outputs the inputs as one sequence which is identical to a selector 97 of Tong et al., that is, the component receives information symbol sequences and parity symbol sequences, internally process the received sequences, and outputs one sequence. However, Tong et al does **not** disclose a multiplexer for generating a new parity symbol sequence by multiplexing interleaved parity symbol sequences, and further, does **not** disclose an operation for serially concatenating the interleaved information symbol sequence and the new parity symbol sequence.

Second, the Examiner asserts that a QCTC generator of the present invention is identical to a repetition generator 96 of Tong et al. Actually, a sub-code can be generated by a puncturing operation or a repetition/puncturing operation by the QCTC generator of the present invention. Therefore, it can be understood that there is a slight relation between the QCTC generator of the present invention and the repetition generator 96 of Tong et al. However, the repetition generator 96 of Tong et al. never provides a definite standard that the QCTC generator selects a predetermined number of symbols. That is, the QCTC generator of the present invention generates the sub-code at a given code rate by selecting the predetermined number of symbols from serially concatenated symbols, here, the selected symbols are started from a starting symbol at a given starting position and

the number of the selected symbols is determined according to the code rate. The repetition generator 96 of Tong et al never disclose the above features.

Third, Tong et al does not disclose a definite condition for an intereleaving operation by an interleaver, however, an interleaver of the present invention satisfies definite conditions outlined in the present application.

Additionally, the Examiner cites the selector 97 of *Tong* as performing both the multiplexing operations and the concatenation operations of Claims 9 and 17. However, *Tong* merely recites that the selector couples the channel interleaved bits accordingly. There is no disclosure in *Tong* that the selector generates a new parity symbol sequence by multiplexing the interleaved symbols of the corresponding parity symbol sequences, and serially concatenates the interleaved information symbol sequence and the new parity symbol sequence.

Finally, it is respectfully submitted that independent Claims 9 and 17 are in condition for allowance. Without conceding the patentability per se of dependent Claims 10-13, and 18-21, they are likewise believed to be allowable by virtue of their dependence on Claims 9 and 17, respectively. Accordingly, reconsideration and withdrawal of the rejections of dependent Claims 10-13 and 18-21 are respectfully requested.

All of the remaining claims pending in the Application, namely, Claims 9-13 and 17-21, are believed to be in condition for allowance. Should the Examiner believe that a telephone conference or personal interview would facilitate resolution of any remaining matters, the Examiner may contact Applicants' attorney at the number given below.

Respectfully submitted,

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PJF/DMO/MJM/las

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Re:	Working Group Review of P802.16-REVd_D3
Abstract	
Purpose	To propose enhancements to the OFDMA PHY in 802.16REVd_D3 draft for better mobility performance.
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OFDMA PHY Enhancements to support Hybrid ARQ

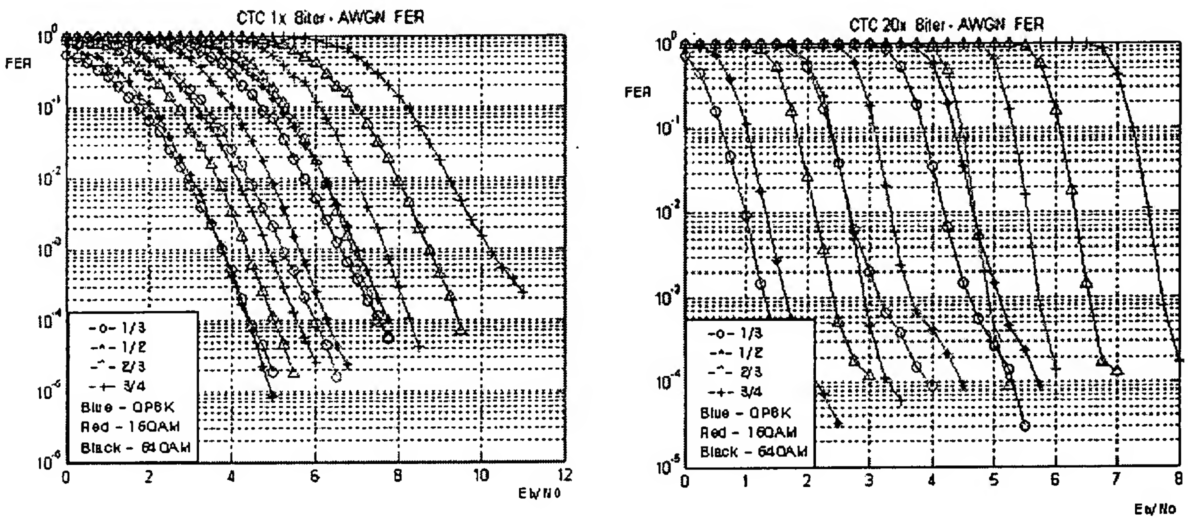
Introduction

In this contribution we propose enhancements to the WirelessMAN OFDMA PHY for better mobile performance by using Hybrid ARQ using CTC.

1 Requirements for the FEC structure

Like other Turbo code families, the convolutional Turbo code (CTC) shows that its link performance is very sensitive to the codeword length. Figure 1 shows the BER performance of various combinations of CTC rate and modulation in AWGN. The number of iteration is eight. Figure 1 (a) and (b) show BER performances when the allocated subchannel(s) are one and 20, respectively. The graphs show that the BER performance for large codeword is superior to the short codeword at most 2.5 dB in Eb/No.

In 802.16, it is assumed that the information bit size for a physical burst varies in large range (from 48 to thousands bits). Thus, it happens to have very short codeword. However, it should be guaranteed that the whole information bits for a burst are to be encoded as one codeword. It makes the coding gain for a long information bits to be maximized.



(A) (B)

Figure1. BER performance of CTC with different codeword size.

In 802.16 OFDMA mode, adaptive modulation and coding (AMC) is exploited against the long and short term fading and path loss. In mobile cellular operation, the difference between channel conditions when it is reported (feedbacked) and it is applied for AMC is inevitable. Thus, any mobile system should provide some countermeasures against the difference. For example, the margin for SNR threshold for each AMC level is possible solution.

It is known that Hybrid Automatic Request (HARQ) is very efficient against the channel quality difference. In case of the previous transmission failure (NACK), HARQ schemes retransmit more redundancy and receiver combines whole redundancy received. The combining makes more SNR and coding gain against the change of channel condition.

There are many variants in HARQ schemes. Among them, chase combining (CC) and incremental redundancy (IR) are sited in many literatures. When the previous transmission is failed CC sends the same copy that was sent in the previous transmission and IR sends part of codeword that may different from previous first transmission. The IR scheme shows better performance due to the additional coding gain over the CC. Thus, the IR scheme is very viable solution for 802.16d OFDMA FEC against the mobility.

For the implementation of IR scheme, the generation of subpackets from the mother codeword is necessary. Further, the subpacket should show a complementary property for better performance.

For CTC and 802.16 OFDMA, the following requirements should be satisfied with FEC structure.

1. The whole information bits for a burst are to be encoded as one codeword
2. FEC structure should support IR type HARQ scheme.
3. For the support of IR type HARQ scheme, the subpacket should show complementary property.

2 Proposed DL/UL FEC structure for OFDMA mode

Generation of CTC encoded codeword

The mother code is rate 1/3 convolution Turbo code (CTC) and the polynomials defining the connections are described in octal and symbol notations as follows:

- For the feedback branch: 0xB, equivalently $1+D+D^3$ (in symbolic notation)
- For the Y parity bit: 0xD, equivalently $1+D^2+D^3$
- For the W parity bit: 0x9, equivalently $1+D^3$

The 1/3 CTC shows better BER performance over 1/2 CTC. Figure 2 compares BER performance of the two codes. The more coding gain will be reflected on the HARQ performance too. The increase of coding gain is minimal with the lower code rate CTC.

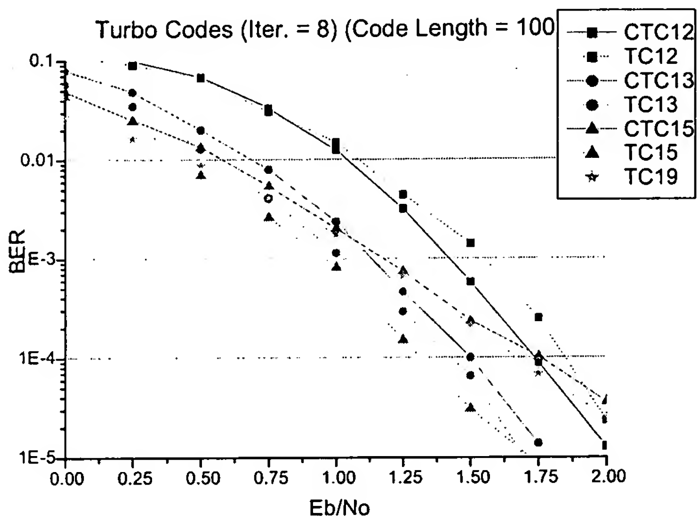


Figure 2. BER performance of 1/2 CTC and 1/3 CTC

The whole information bit sequence of length Nep is encoded into a codeword of length 3*Nep. Nep is limited to the allowable number of {48, 96, 144, 192, 288, 384, 480, 960, 1920, 2880, 3840, 4800}. Because the increase of CTC coding gain is saturated when the length of input is larger than 5000 bits the maximum of Nep is 4800. Figure 3 shows block diagram of CTC encoder. The output sequence is represented as follows.

$$A,B,Y_1,W_1,Y_2,W_2 =$$
$$A_1,A_2,\ldots,A_N,B_1,B_2,\ldots,B_N,Y_{11},Y_{12},\ldots,Y_{1N},W_{11},W_{12},\ldots,W_{1N},Y_{21},Y_{22},\ldots,Y_{2N},W_{21},W_{22},\ldots,W_{2N}$$

CTC interleaving scheme is same as described in the current 802.16dr3 specifications except the new parameters for the allowable Nep.

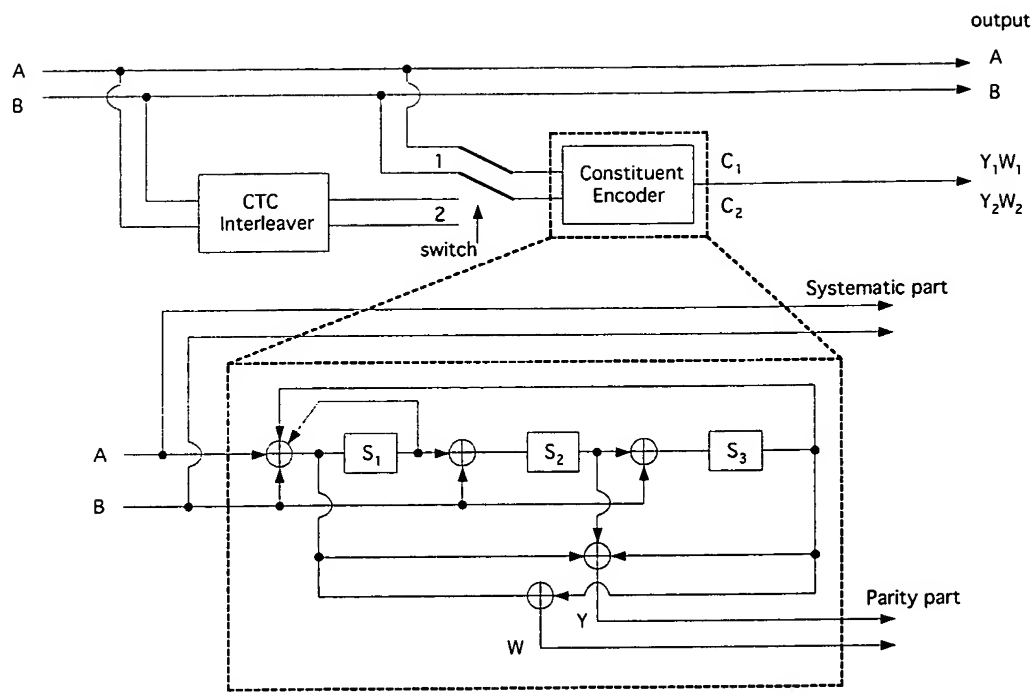


Figure 3. Block diagram of rate 1/3 CTC encoder

Subpacket generation

Proposed FEC structure punctures mother codeword to generate subpacket with various coding rates. The subpacket is also used as HARQ packet transmission. Figure 4 shows block diagram of subpacket generation. 1/3 CTC encoded codeword goes through interleaving block and the puncturing is performed. The puncturing is performed to select the consecutive interleaved bit sequence that starts at any point of whole codeword. For the first transmission, the subpacket is generated to select the consecutive interleaved bit sequence that starts from the first bit of the systematic part of the mother codeword. The length of the subpacket is chosen according to the needed coding rate reflecting the channel condition. The first subpacket can also be used as a codeword with the needed coding rate for a burst where HARQ is not applied.

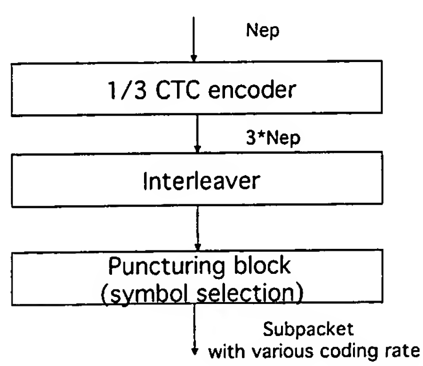


Figure 4. Block diagram of subpacket generation

Interleaving block: QCTC (Quasi Complementary Turbo Code)

A puncturing process is very common to generate various coding rates with Turbo code families. However, the puncturing should guarantee the complementary characteristics of the punctured codeword. In other words, the parity bits of the punctured codeword should be chosen uniformly from the parity bits of a constituent encoder. The parity bits of the punctured codeword should have even number of parities from the two constituent encoders. We call such Turbo code as complementary Turbo code. Because the puncturing is just a simple process to select the subpacket, the proposed FEC structure rely such complementary property on the

interleaving block.

Figure 5 shows block diagram of the interleaving scheme of the proposed FEC structure. At first, the CTC encoder output is separated into a sublock. Then the interleaving is applied for the bit sequence within the sublock. It guarantees the uniformity of the interleaved codeword. Next, Symbol grouping is performed such that the parity bits from the two constituent encoders are interlaced bit by bit. The systematic part of the 1/3 CTC encoder is located at the head of the interleaved codeword. In this way, the proposed FEC structure ensures the quasi complementary characteristics of the interleaved codeword and thus, complementary characteristics of the subpacket. We just say "quasi complementary" for the case of breaking the complementariness of few bits after puncturing.

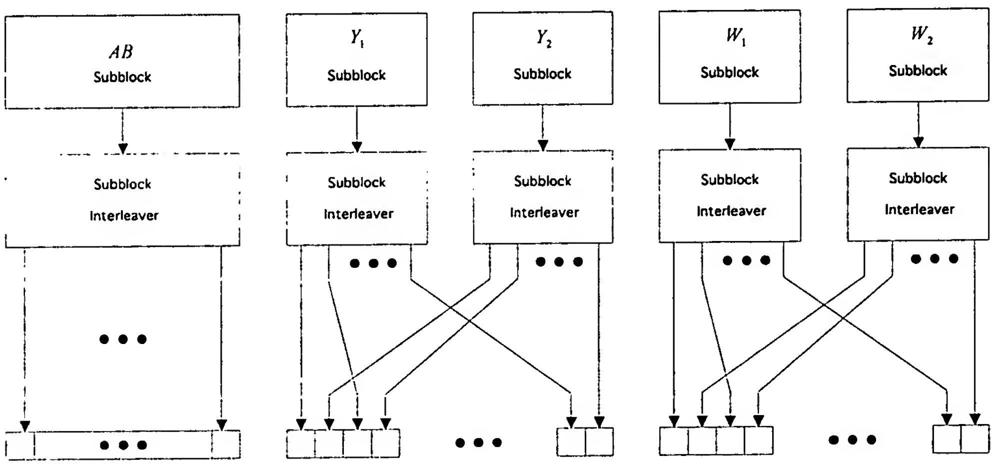


Figure 5. Block diagram of the interleaving scheme

Symbol selection

Lastly, symbol selection is performed to generate the subpacket. We call the puncturing block as the symbol selection in the viewpoint of subpacket generation.

Mother code is transmitted with one of subpackets. The symbols in a subpacket are formed by selecting specific sequences of symbols from the interleaved CTC encoder output sequence. The resulting subpacket sequence is a binary sequence of symbols for the modulator.

Let

- k be the subpacket index when HARQ is enabled. k=0 for the first transmission and increases by one for the next subpacket;
- N_{EP} be the number of bits in the encoder packet (N_{EP} = 48, 96, 144, 192, 288, 384, 480, 960, 1920, 2880, 3840, 4800);
- N_{SCHk} be the number of subchannel(s) allocated for the k-th subpacket (1~480);
- m_k be the modulation order for the k th subpacket ($m_{k=0}$ = 2 for QPSK, 4 for 16QAM, and 6 for 64-QAM); and
- $SPID_k$ be the subpacket ID for the k-th subpacket, (for the first subpacket, $SPID_{k=0} = 0$).

Also, let the scrambled and selected symbols be numbered from zero with the 0-th symbol being the first symbol in the sequence. Then, the index of the i-th symbol for the k-th subpacket shall be

$$S_{k,i} = (F_k + i) \bmod (3 * N_{EP})$$

where $i = 0 \ to \ L_K - 1$,

$$L_k = 48 * N_{SCHk} * m_k \text{, and}$$

$$F_k = (SPID_k * L_k) \bmod (3 * N_{EP}) .$$

The N_{EP}, N_{SCHk} , and SPID values are determined by the access point and are provided to the access terminal through the MAP bursts. The m_k parameter is determined in the next subsection. The above symbol selection makes the followings possible.

1. The first transmission includes the systematic part of the mother code. Thus, it can be used as the codeword for a burst where the HARQ is not applied.
2. The location of the subpacket can be determined by the SPID itself without the knowledge of previous subpacket. It is very important property for HARQ retransmission.

Selection of Modulation order

Modulation order (m_k) is determined by the number of bits per subcarriers. For the same Nep, smaller number of the allocated subchannels (Nsch) means low coding rate and low modulation order, the larger number of the allocated subchannels (Nsch) means higher coding rate and higher modulation order. For DL, the modulation order (2 for QPSK, 4 for 16QAM, and 6 for 64QAM) shall be set for all the allowed transmission formats. For UL, only QPSK and 16 QAM are allowed.

The current 802.16d OFDMA mode, modulation order is determined by the channel condition. So the above description looks different. However, the modulation order determined also reflects the channel condition. Once the modulation order is determined for each Nep and Nsch combination, one can determine SNR threshold for each combination. Then the channel conditions reported from each user terminal can decide the possible combinations of Nep and Nsch for the current channel condition for each user terminal. Then, the selection of Nep and Nsch is a task of a system scheduler.

3 Suitability of the proposed FEC structure for CTC and mobility

As described above, the proposed FEC structure is suitable for CTC and mobile operation of cellular operation.

1. Full exploitation of CTC coding gain:
   - A. The proposed structure encodes the whole information bit sequence of length Nep as one codeword.
   - B. The proposed structure can generate the punctured codeword with various coding rate. The punctured codeword shows the property of QCTC which guarantees its CTC coding gain.
2. Efficient HARQ support:
   - A. The proposed structure generates subpackets for HARQ transmission.
     - i. The subpackets show the property of QCTC which guarantees its CTC coding gain.
     - ii. IR scheme is possible (The subpacket can be different from the previous subpacket).
     - iii. The location of each subpacket is independent of the previous subpacket.

4 Conclusions

The proposed FEC structure satisfies the CTC and mobile cellular operation of 802.16d OFDMA mode.

5 H-ARQ operation

H-ARQ (Hybrid Automatic Repeat reQuest) can be used to mitigate the effect of channel and interference fluctuation. H-ARQ renders performance improvement due to SNR gain and time diversity achieved by combining previously erroneously decoded packet and retransmitted packet, and due to additional coding gain by IR (Incremental Redundancy). Figure 1 illustrates the throughput difference between H-ARQ and other scheme. The rightmost orange line depicts the system throughput of conventional ARQ scheme without soft combining, the blue line depicts that of Chase combining, and the leftmost pink line depicts that of IR. As can be seen in the figure, Chase combining can expand the operating region by 3dB over conventional ARQ scheme without soft combining, and IR can expand it by additional 2dB. This can be greatly beneficial to the system operation. In fading channels with terminals in motion, the received SNR would be in very broad region in contrast to AWGN channel. In such a case, call drop may be frequent even if multiple retransmission is performed without soft combining. However with soft combining, the operating region would be expanded to enable the reliable communication. In brief, H-ARQ is the technique proposed to overcome the adaptation error of the AMC(Adaptive Modulation and Coding) in fading channel.

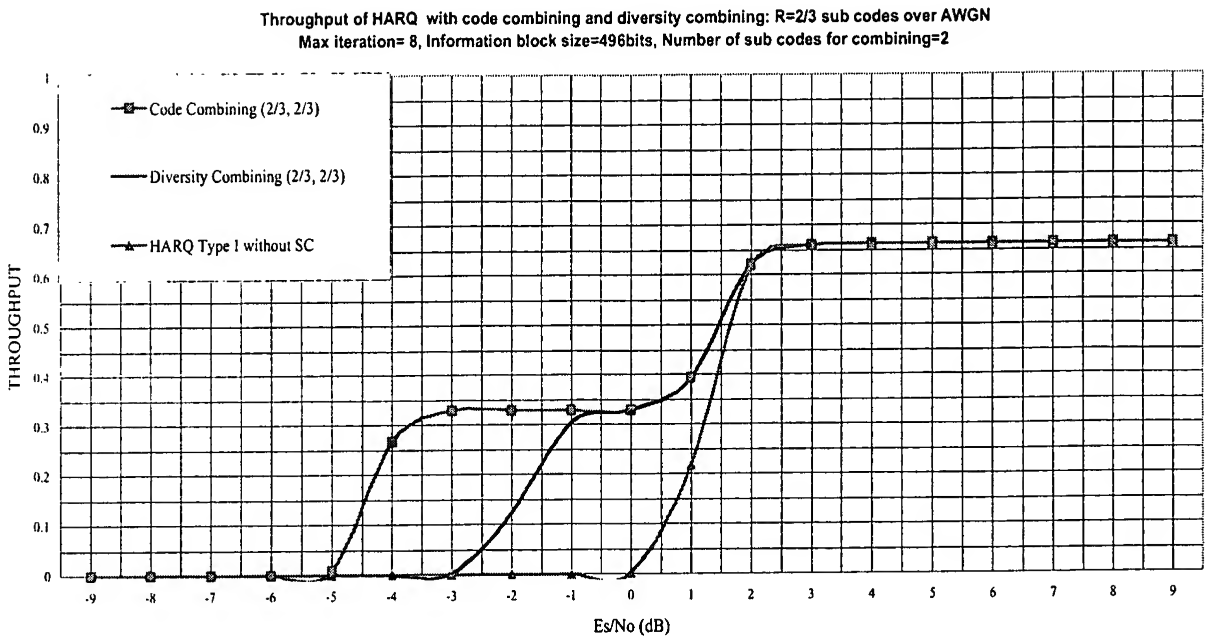


Figure 1. Soft combining gain in H-ARQ

6 PHY and MAC support for HARQ

Subpacket generation
The proposed FEC provides quasi complementary Turbo code (QCTC) structure. Due to QCTC structure, the subpackets for H-ARQ can be efficiently generated.

DL/UL ACK/NAK signaling
For DL/UL H-ARQ, fast ACK/NAK signaling is necessary. For the fast ACK/NAK signaling of DL H-ARQ channel, a dedicated PHY layer ACK/NAK channel is designed in UL. For the fast ACK/NAK signaling of UL H-ARQ channel, H-ARQ ACK bit-map IE is designed and the IE will be inserted in MAP.

H-ARQ parameter signaling
The parameters for each subpacket should be signaled independent of the subpacket burst itself. The parameters for each subpacket include SPID (Subpacket Identifier. The BS shall set this field to the subpacket identifier for the subpacket transmission.), ACID (ARQ Channel Identifier. The BS shall set this field to the ARQ channel identifier for the subpacket transmission.), and AI_SN (ARQ identifier sequence number. This toggles between '0' and '1' on successfully transmitting each encoder packet with the same ARQ channel.). For the signaling of those parameters, new H-ARQ Control IE is defined and the IE is to be placed in a MAP IE for a burst where H-ARQ is enabled.

Quasi-Complementary Turbo Codes (QCTC) For Applications In High-Data-Rate Systems

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Abstract: **The quasi-complementary turbo codes (QCTC) proposed by Kim [1] is used for a fast hybrid ARQ scheme with incremental redundancy and adaptive modulation coding in the cdma2000 1xEV-DV [2]. The QCTC provides various code rates with good performance, a very simple encoder structure, and an inherent channel interleaving. It is shown that the QCTC is a unified scheme of channel coding and channel interleaving. In this paper, we introduce the properties of QCTC and various hybrid ARQ-QCTC schemes for the system.**

I. INTRODUCTION

The latest release of cdma2000 1x standards, referred to the Release C or 1xEV-DV (the 1x evolution with data and voice), significantly increases the efficiency of the air interface by introducing a new packet channel with a peak data rate up to 3.09Mbps [2]. To support efficient mobile communications, adaptive modulation and coding (AMC) and fast hybrid ARQ schemes (automatic repeat request) have been considered. The quasi-complementary turbo codes (QCTC) proposed by Kim [1] has been used for both AMC and fast hybrid ARQ with incremental redundancy (IR).

In the 1xEV-DV, a fast hybrid ARQ scheme using asynchronous and adaptive incremental redundancy (A^2IR) has been investigated to maximize channel utilization. In order to support A^2IR, flexible turbo codes were required with providing variable code rates and various redundancy patterns, maintaining backward compatibility, and achieving the maximal coding gain with soft combining. For lots of combinations of code rates and modulations more than 600 cases in A^2IR, conventional hybrid ARQ schemes using optimal puncturing patterns such as the rate compatible punctured turbo codes (RCPT) or the rate compatible punctured convolutional codes (RCPC) can not be used due to their complexity [3]-[5]. Furthermore, RCPC or RCPT is used for a fixed code rate and fixed puncturing period. On the other hand, the A^2IR has requested flexible combinations of code words with different rates, code bit composition, and puncturing periods. In addition, a channel interleaving must be performed before a redundancy selection to avoid storing all possible interleaving or deinterleaving patterns according to packet sizes.

In [6], the complementary punctured convolutional (CPC) codes have been introduced. Similarly, in this paper, the quasi-complementary turbo codes (QCTC) is defined as a set of punctured or repeated turbo codes derived from the same original low rate code if they are almost equivalent in terms of their distance properties, and the code bits on two codes in QCTC are almost logical complements of each other, and they yield at least the original low rate code by combining. The QCTC has additional properties such as balance of constituent encoders, uniform puncturing, and uniformly distributed symbol energy level in a decoder. Based on the QCTC, we propose and analyze a variation of type II and III hybrid ARQ-QCTC schemes with AMC. Packets that are detected in error are not discarded, but are combined softly with a new packet provided by the transmitter to help recover the transmission message.

In general, convolutional codes have equal code bit error sensitivity with a maximum likelihood decoding such as Viterbi algorithm. So, the performance of convolutional codes is good such that "*self-decodable*," only if a code rate is less than 1.0 [8], [9]. However, the situation is different in turbo codes. Unlike convolutional codes, turbo codes have unequal bit error sensitivity. The systematic puncturing provides better performance than that of nonsystematic puncturing as code rate increase [7]-[9]. Turbo codes are usually composed of two constituent encoders linked by a turbo interleaver. Since a maximum likelihood decoding is practically impossible in turbo codes, an iterative decoding algorithm is frequently used that works on the individual trellis of a constituent code at each time [10]. This implies that actual code rate of constituent code can be greater than 1.0 although the overall code rate of turbo code is smaller than 1.0. For example, the decoding fails if the actual code rate of constituent code is greater than 1.0 although the extrinsic information provides the reliable information. We introduce a criterion for "*self-decodable turbo codes.*" The QCTC is designed to avoid the situation by the proposed encoder structure and the puncturing-repetition method.

In section II, we present an overview of the QCTC and its properties. In Section III, we provide several transmission protocols for a type II and III hybrid ARQ-QCTC schemes. Section IV contains numerical results and an analysis of performance of QCTC in the cdma2000 1xEV-DV. Finally, in Section V, the conclusions are given.

II. QUASI-COMPLEMENTARY TURBO CODES

In a conventional physical layer structure of wireless communication systems, the fixed channel interleavers and puncturing-repetition are used after a channel encoding. However, that structure has a problem using an AMC with incremental redundancy due to lots of code rates and puncturing-repetition patterns.

A. Construction of a Family of QCTC

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The encoder structure of quasi-complementary turbo codes is given in Fig. 1. The encoder of QCTC consists of two parts such as a conventional turbo encoder with code rate R and a proposed permutation block where systematic symbols X and parity symbols of Y_0, Y_1, Y'_0, Y'_1 are separated into sub-blocks, respectively [11]. Each sub-block has a sub-block interleaving to randomize input symbols as well as to maintain uniformity of puncturing in systematic symbols and parity symbols independently. After that, the permuted parity symbols are interlaced each other to provide uniform puncturing and the balance of number of punctured symbols. The QCTC symbol selection block performs the formation of sub-code word every transmission. The number of QCTC code symbols is same as in a turbo code with code rate of R. In the QCTC, the separation of systematic symbols is used in order to enhance performance of a high rate turbo code. The details are given in the following section.

The RCPC or RCPT usually uses various puncturing patterns that are optimized with a fixed puncturing period for each code rate [3], [4]. So, it may not be optimal to use those patterns for each code if a code rate changes every transmission. On the other hand, QCTC provides all combinations of different code rates and redundancy patterns for every transmission as it maximize a coding gain of a combined code. Therefore the QCTC is regarded as a two dimensional turbo code for an adaptive incremental redundancy scheme such that code rates and puncturing patterns are selected simultaneously. The QCTC uses a flexible puncturing period that is determined automatically by a code rate and an initial position for the QCTC symbol selection. It is different to the RCPC and the RCPT using a constant puncturing period. The symbol repetition is used and is performed sequentially on the overall code symbols if a code rate is lower than R.

B. QCTC Interleaving and Its Properties

The QCTC interleaving uses the interlacing of parity symbols and the partial bit reverse order (PBRO) interleaving defined in equation (1). N is an interleaver block size and an operator 'mod' means modular operation with J. Parameters m and J are determined by N. The BRO interleaving is regarded as a special case of PBRO interleaving with J=1. For example, with m of 4, $BRO_4(12)$ is equal to 3 because 12 equals (1100) in binary representation.

$$A_i = 2^m (i \bmod J) + BRO_m(\lfloor i/J \rfloor) \quad (1)$$

where $i=0, 1, \ldots, N-1$, and $N = 2^m \times J$.

For the pruning or the puncturing, the QCTC uses specific property of BRO. The BRO provides almost uniform puncturing patterns with the pruned symbols. Let's assume that a code word is interleaved by BRO and then last N_{PR} symbols from the end of the code word are pruned for a code rate matching. Then BRO gives that the pruned code symbols are distributed almost uniformly after BRO de-interleaving. For example, the following equation shows that the distance between the last two symbols after BRO is 2^{m-1} such that the half of block length N $(=2^m)$.

$$d_m^{BRO}(c_{2^m-1}, c_{2^m-2}) = \left|(2^m - 1) - \sum_{j=2}^{m-1} 2^{m-j}\right| = \frac{2^m}{2} \quad (2)$$

In terms of channel interleaving, the proposed QCTC interleaving has similar interleaving depth compared to the cdma2000 full channel interleaving. Because of the input symbols are permuted by individual sub-block interleaver and they are interlaced each other. The exact interleaving depth comparison between them is under investigation due to no exact performance analysis of turbo codes. However, the intensive simulations have shown that the performance of QCTC interleaving is better or equals to that of full channel interleaving. The BER performance comparisons are given in Table 2 and 3, respectively.

In order to select the optimal parameter m and J for a given N, two criteria are introduced. First, a distance between adjacent interleaved symbols after interleaving is used for measuring randomness for channel interleaving gain. Second, the difference of distances given in the first criterion is used for measuring uniformity in puncturing. In Table 1, the parameters of sub-block interleaving are given for the encoder packet sizes N_{EP} in the cdma2000 1x EV-DV. If N_{EP} is less than N $(=2^m \times J)$, then the tentative interleaved address in sub-block interleaving is accepted as an output address only if it is less than N_{EP}. Otherwise, discard it. Interlacing corresponding to each sub-block performs the uniform distribution of parity symbols to each constituent encoder and increases the randomness of QCTC interleaving. The number of parity symbols of each constituent encoder is always same or different with one at most.

Table 1. Sub-block Interleaving Parameters

Sub-block Interleaver ($N=2^m \times J$)			
$N_{EP}=(2^m \times (J-1)+q)$	N	m	J
$408(=2^7 \times 3+24)$	512	7	4
$792(=2^8 \times 3+24)$	1024	8	4
$1560(=2^9 \times 3+24)$	2048	9	4
$2328(=2^{10} \times 2+280)$	3072	10	3
$3096(=2^{10} \times 3+24)$	4096	10	4
$3864(=2^{11} \times 1+1816)$	4096	11	2

C. High Rate Turbo Codes and Iterative Decoding

In Fig. 2, a turbo code of code rate of 1/5 and the corresponding SISO decoder are given. Let us assume that the information block length is L bits. To make a code with code rate of R_s=4/5, we have to select $5L/4$ among $5L$ code bits. Let us assume that a random permutation is used in the symbol selection block in order to uniformly distribute systematic symbols and parity symbols. Then, the actual code rate R_1 of the first constituent decoder in Fig. 2 is $4/3$ because only $3L/4$ input code symbols such as $L/4$ systematic symbols, $L/4$ Y_0 parity symbols, and $L/4$ Y_1 parity symbols contributes the first decoder. The situation is same in the second constituent decoder. Therefore it can not be expected for an R-4/5 turbo code to have good performance. In high rate turbo codes, the following criterion is strictly required for good performance.

Criterion for *self-decodable* turbo codes

*The turbo code is **self-decodable** if and only if a turbo code has code rates of each constituent code less than 1.0. It is equal to that*

$$\forall k \left(N^S + N_k^P\right) > P. \quad (3)$$

where k is an index for a constituent encoder and K is the number of constituent encoders. N^S and N_k^P mean the number of systematic symbols and the number of parity symbols of kth constituent code in a puncturing matrix A with a puncturing period P, respectively.

From (3), two necessary conditions are induced for the symbol selection of turbo codes in a type II or III hybrid ARQ scheme. First, it is better to select the systematic symbols for a given code rate R_s. Because of the systematic symbols are counted in every constituent code. Second, the criterion will be satisfied as much as the puncturing period P increases through increase of freedom of code symbol selection. According to the criterion and analysis, it is shown that a turbo code is likely to have decoding failure if a code rate R_s is greater than 3/5 under an uniform distribution of systematic and parity symbols. The QCTC is designed to avoid the situation and to mitigate the impact by adopting the proposed encoder structure and the puncturing method.

D. Soft Combining

A hybrid ARQ scheme with soft combining has the inherent imbalance of symbol energy level due to symbol combining according to a retransmission protocol. So, the imbalance of symbol energy levels should be minimized as possible as a hybrid ARQ scheme can do. A hybrid ARQ-QCTC scheme resolves this issue by transmitting code symbols sequentially on the circle that is a code word with code rate of R. At the receiver, the initial packet and retransmitted packets are combined on the circle. The symbol energy levels are accumulated if the number of code symbols becomes larger than L/R where L is the information block length. The normalized symbol repetition factor (or energy level) $\overline{N}_{SR}$ is given by (4) where N_{TS} is the total number of received code symbols. So, all symbols are repeated as much as $\overline{N}_{SR}$ and the rest symbols are distributed evenly over them. So, QCTC provides the balanced code symbol energy levels in a turbo decoder regardless of the number of retransmission and soft combining.

$$\overline{N}_{SR} = \left\lfloor \frac{N_{TS}}{L/R} \right\rfloor \quad (4)$$

III. HYBRID ARQ SCHEMES USING QCTC

A. Sub Packet Formation with QCTC

It is assumed that transmission and re-transmission units for incremental redundancy are the sub-packets where the QCTC are used for sub-packet formation. The encoder packet can have various sub-packets. Let the sub-code rates be R_i, $i=0,1,2,\ldots, N_{sc}-1$, where N_{sc} is the number of possible sub-code rate R_i. Let the sub-code set size be S_i that is the number of code words in C_i. Then a QCTC sub-code C_{ij}, $j=0,1,2,\ldots,S_i-1$ in S_i and R_i are defined as a sub-code. The transmitter sends sub-code C_{ij} corresponding to the sub-code rate and incremental redundancy.

An example of encoder packet encoding and sub-packet formation with the QCTC is depicted in Fig. 3. Three sub-code sets are used for sub-packet formation in which R_0, R_1, and R_2 are 1/7, 2/7, and 4/7, respectively. For a conventional type II or type III hybrid ARQ scheme with a fixed code rate of R_0, the sub-codes C_{0j}, $j=0, 1, 2, \ldots, S_0-1$ are used. Another example is depicted in Fig. 4. Three sub-code sets are used randomly for sub-packet formation. Any sub-codes C_{ij} is selected according to sub-code rate and incremental redundancy at each time. As it is shown, any combination of sub-codes is possible in the QCTC symbol selection and sub-packet formation [11].

B. QCTC Symbol Selection Modes

The code symbol selection for sub-packets is performed according to sub-packet sizes, data rates, encoder packet sizes, and available Walsh codes in the cdma2000 1xEV-DV. Let k and N_{EP} be the sub-packet index and the number of bits in the encoder packet, respectively. Let $N_{Walsh,k}$ be the number of 32-chip Walsh channels for the k-th sub-packet and let $N_{slots,k}$ be the number of 1.25-ms slots for the k-th sub-packet. Finally, let m_k be the modulation order for the k-th sub-packet ($m_k = 2$ for QPSK, 3 for 8-PSK, and 4 for 16-QAM). It is assumed that the symbols in the concatenated sequence of QCTC symbols are numbered from zero. Let $L_{SC,k}$ be the length of the k-th sub-packet and $F_{s,k}$ and $L_{s,k}$ be the positions of the first symbol and the last symbol of the k-th sub-packet, respectively. It is assumed that $SPID_k$ is the sub-packet ID for the k-th sub-packet and has value of 0, 1, 2, or 3. For all modes, the initial packet has to use $F_{s,0}$ of zero [2], [11].

SSPM (Sequential Starting Point Mode)

The positions of the first and last symbols of sub-packets are determined by the N_{EP} and $L_{SC,k}$. All sub-codes are linked each other sequentially at the receiver. The SSPM has the advantage of maximizing a coding gain but it has the disadvantage in terms of robustness in missing sub-packets. If a previous sub-packet is missed then error propagation can occur for that encoder packet.

$$L_{SC,k} = 1536 \times \frac{N_{Walsh,k}}{32} \times m_k \times N_{slots,k} \quad (5)$$

$$F_{s,k} = (L_{s,k-1} + 1) \bmod (5 \times N_{EP}) \quad (6)$$

$$L_{s,k} = \left(F_{s,k} + L_{SC,k} - 1\right) \bmod (5 \times N_{EP}) \quad (7)$$

FSPM (Fixed Starting Point Mode)

For a simple protocol for a type III hybrid ARQ scheme, the starting position of sub-packet can be fixed to $g(SPID_k)$ corresponding to $SPID_k$. The $g(SPID_k)$ is a predetermined constant in [0, $5N_{EP}-1$]. The advantage is that a receiver can know the exact first symbol position regardless of missing previous packets and there is no error propagation as in the SSPM. However, the FSPM has performance degradation

due to imperfect concatenation of sub-codes. In FSPM, the $SPID_k$ is determined by a transmitter to minimizing the latency (puncturing) or the overlapping (repetition) between consecutive sub-packets as in (9). On the other hand, a receiver knows the exact $F_{s,k}$ by the received $SPID_k$ directly without examination. $L_{SC,k}$ and $L_{s,k}$ are same as in (5) and (7), respectively.

$$F_{s,k} = g(SPID_k) \tag{8}$$

$$SPID_k = \begin{cases} 0 & for\ k=0 \\ \min\limits_{n\in\{1,2,3\}}^{-1} \left| \left[g(SPID_n) \bmod (5\times N_{EP}) \right] - L_{s,k-1} \right| & otherwise \end{cases} \tag{9}$$

PCCM (Partial Chase Combining Mode)

For a Chase combining (a type I hybrid ARQ), the first position $F_{s,k}$ of sub-packet corresponding to all $SPID_k$ is fixed to zero [12]. If the length of sub-packet is not constant (or sub-code rate is not a constant) then this protocol supports the partial Chase combining (PCC). $L_{s,k}$ is same as in (7).

IV. NUMERICAL RESULTS

Simulations were performed to analysis the properties of QCTC and to estimate the throughput of various hybrid ARQ-QCTC schemes and compare performance with that of reference systems. The Max-log-MAP algorithm was used for a turbo decoding. In these simulations, the encoder packet sizes and modulations such as QPSK, 8-PSK, and 16-QAM were used in the cdma2000 1xEV-DV. A rate-1/5 turbo code with constraint length 4 was used [2].The channel was assumed to be an AWGN channel. A 16 bits CRC code in [2] was used to detect errors. For a soft metric, we have used the dual minimum metric (DMM). The throughput η is defined as N_{EP}/N_T where N_T is the total number of transmitted bits per the correctly decoded encoder packet.

In Fig. 5, the packet error rates for various code rates are given for the encoder packet size of 3072 and 16-QAM. The QCTC has shown consistent PER that can be estimated by the rate loss from R-1/5. In Fig. 6, the throughput of SSPM and PCCM are shown where the initial sub-code rate is 4/5 and maximum two retransmissions are allowed. The encoder packet of 3072 and 16-QAM were assumed. The ratio in dB between the energy accumulated over one PN chip period (E_C) to the total transmit power spectral density, Ec/Ior, is fixed to -1.0dB [2], [11]. The SSPM yields remarkable throughput gain about 3.5dB compared to Chase combining with a retransmission and the performance gap becomes larger as the retransmission increases. In Fig. 7, we have compared the performance of SSPM and FSPM. The encoder packet of 1536, QPSK modulation, and Ec/Ior of -1.0dB were assumed. The SSPM showed better performance than that of FSPM as it could be expected by the degradation of coding gain due to discontinuity in FSPM.

V. CONCLUSIONS

We have presented in this paper a new class of turbo codes called the quasi-complementary turbo codes (QCTC) and analyzed various type II and III hybrid ARQ-QCTC schemes with adaptive modulation and coding (AMC). The advantage is that the QCTC provides various code rates with good performance, a very simple encoder structure, and an inherent channel interleaving. These features are desirable especially in the AMC with incremental redundancy. It was shown that the systematic puncturing is required to maintain good performance with high rate turbo codes and an iterative decoding can limit the maximal code rate of turbo code in hybrid ARQ schemes. The QCTC is a unified scheme of channel coding and channel interleaving and has been adopted in the cdma2000 1x EV-DV.

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TABLE 2. BER of QCTC and a full channel interleaver (R=1/5).

Vehicle speed (Km/h)	Eb/Nt(dB)	BER	
		Full Channel	QCTC
120	4.0	3.04E-02	3.05E-02
	8.0	1.34E-03	1.28E-03
30	6.0	2.99E-02	2.91E-02
	10.0	5.00E-03	4.88E-03
3	8.0	5.00E-02	4.98E-02
	12.0	2.08E-02	2.04E-02

TABLE 3. BER of QCTC and a full channel interleaver (R=1/3).

Vehicle speed (Km/h)	Eb/Nt(dB)	BER	
		Full Channel	QCTC
120	6.0	2.42E-02	2.17E-02
	10.0	1.29E-03	1.13E-03
30	8.0	2.60E-02	2.42E-02
	13.0	2.89E-03	2.73E-03
3	9.0	4.99E-02	4.35E-02
	20.0	3.33E-03	3.02E-03

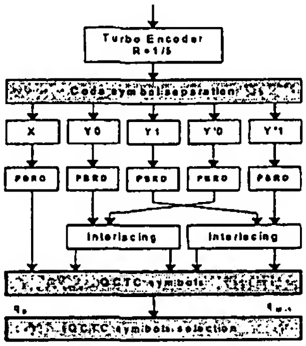

Fig. 1. QCTC encoder structure and symbol selection.

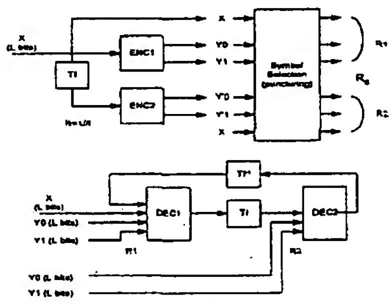

Fig. 2. High rate turbo codes and actual sub-code rates

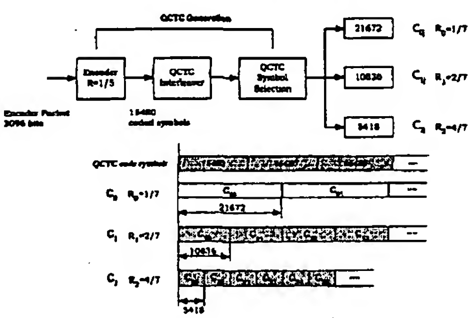

Fig. 3. Encoder packet encoding and sub-packet formation.

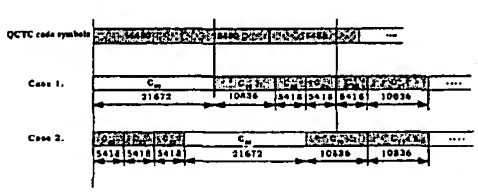

Fig. 4. Encoder packet encoding and sub-packet formation.

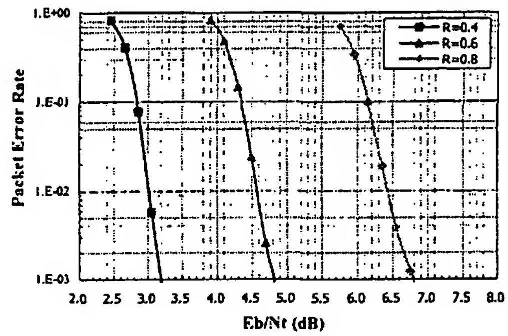

Fig. 5. Packet Error Rate of EP=3072 and 16QAM according to code rates

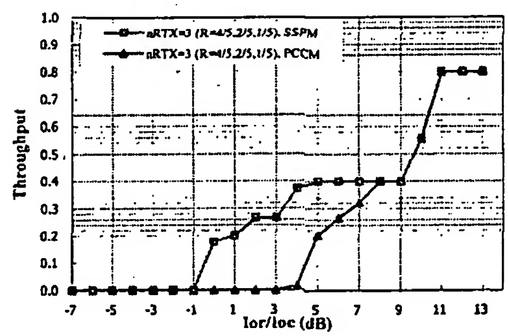

Fig. 6. Throughput of EP=3072 and 16QAM with R of 4/5.

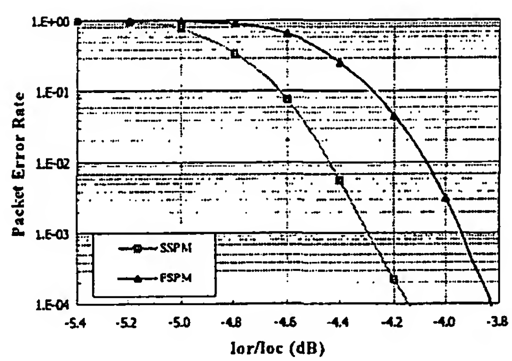

Fig. 7. Packet error rate of SSPM and FSPM with R=1/3 and QPSK.